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The CARLIT method for the assessment of the ecological quality of European Mediterranean waters: Relevance, robustness and possible improvements

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ABSTRACT

The application of the European Union (EU) Water Framework Directive (WFD) requires the assessment of the ecological status (ES) of coastal waters in order to detect environmental changes and implement management plans to prevent their further deterioration. The ES of a water body (WB) has to be assessed on the basis of the status of several biological indicators, referred to as biological quality elements (BQE), such as phytoplankton, macroalgae, seagrasses, macroinvertebrates and fish. We present the most extensive assessment ever undertaken of the ES of Mediterranean waters, by means of the CARLIT index, the most widely used index for the Mediterranean Sea. This index is based on the Ecological Quality Ratio (EQR) between a measured value of Ecological Quality (EQ) and a value corresponding to a reference site. This assessment is based on an extensive field study, covering the whole of the Mediterranean French coasts (including Corsica), 40 WBs and ~2 970 kilometres of shore (at a 1/2 500 scale). The original Ballesteros CARLIT method is compared to the Nikolić modified method, and we have undertaken the challenge of developing an alternative new simplified CARLIT method. This simplified method, which requires less expert judgement, is easier to implement by local authorities, and provides results similar overall to those of the original method. Previous attempts, if any, to correlate EQRs with anthropogenic stressors (through pressure indices) were mainly based upon land uses or on comprehensive lists of stressors, some spatially very sporadic, temporally highly variable, non-representative of the WB and with the impact poorly established on species and communities. To date, the LUSI (Land Uses Simplified Index) and the MA-LUSI-WB have been the most widely used pressure indices. Here, we propose a new pressure index (HAPI) taking into consideration the possible shortcomings of previous indices. It takes into account the actual pressures at community levels considered by the CARLIT method. It accounts well for the EQR values of the study area, as evidenced by the high correlation coefficient between EQRs and HAPI, better than that of the other pressure indices. The present study provides a comprehensive view of the ES of the French Mediterranean coasts. Surprisingly, the picture is far less cause for concern than expected, although this could result from an artefact due to the focus on superficial waters and habitats inherent to the CARLIT method. Where two successive assessments were performed (23 WBs, 2007–2010 vs 2012–2015), the results were similar, which stresses the robustness of the method and/or the relative stability over time of the overall ES of the WBs, and suggests that the successive assessments could be carried out at low frequency.

1. Introduction

The coastal shore is an area that is strongly influenced by anthropogenic pressures, e.g. the constant growth of the population and its socio-economic activities, including agriculture, fisheries and aquaculture, industry and tourism. Coastal marine ecosystems are heavily affected throughout the world. The impact on the

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environment is multiple and cumulative, including habitat destruction, overfishing, pollution, species introduction, sea-level rise and global warming. None of these pressures is isolated and their cumulative effects impact the coastal marine ecosystems and their ability to deliver ecological goods and ecosystem services (Worm et al., 2006; Halpern et al., 2008; Waycott et al., 2009).

Monitoring networks have been set up in order to better understand the putative impact of anthropogenic pressures on various biotopes (Mann, 2000). The European Union (EU) has introduced legislative measures to mitigate the impact on ecosystems of anthropogenic pressures. Since the early 1990s, the EU has adopted framework legislation to regulate the sustainable use of the environment, while protecting, and where necessary restoring, the good quality of the environment. In the framework legislation Birds and Habitats Directives (Council Directive 79/409/EEC, 1979 amended by Council Directive 2009/147/EC, 2009 and Council Directive 92/43/EEC, 1992), the EU established a list of rare and threatened species, and rare natural habitat types, which are protected in their own right (Member States), to designate a network of protected sites ('Natura 2000 sites'). While these Directives also took into account the marine realm, more recently the EU Marine Strategy Framework Directive, MSFD, (Council Directive 2008/56/EC, 2008) established a specific framework for conservation in the field of marine environmental policy. The application of the European Water Framework Directive, WFD (Council Directive 2000/60/EC, 2000) requires the assessment of the ecological status of coastal waters in order to detect environmental changes and implement management plans to prevent their further deterioration. This EU Directive recommends working on the basis of water bodies (WB). France has 11 523 surface WBs (rivers, lakes, transitional waters, and coastal waters) and 574 groundwater WBs. Of the 180 coastal WBs on French coastlines, only 47 are situated along the French Mediterranean coast: 33 between the Spanish border and the Italian border and 14 in Corsica (Ifremer, 2015). The ecological status of a WB has to be assessed on the basis of the status of several biological indicators referred to as Biological Quality Elements (BQE), such as phytoplankton, macroalgae, seagrasses, macroinvertebrates and fishes, and hydro-morphological and physico-chemical quality elements.

To assess the ecological status of coastal water bodies in the WFD, a wide range of biological indices using macrophytes as BQE has been developed along the Mediterranean coasts, such as CARLIT (CARtography LITtoral), CCO (Cover Characteristic species Opportunistic species), CFR (Calidad de Fondos Rocosos), EEI (Ecological Evaluation Index), E-MaQI (Expert-Macrophyte Quality Index), ICS (Index of Community Structure), MarMAT (Marine Macroalgae Assessment Tool), RICQI (Rocky Intertidal Community Quality Index), and RSL (Reduced Species List) (Panayotidis et al., 1999, 2004; Orfanidis et al., 2001, 2003, 2011; Simboura et al., 2005; Ballesteros et al., 2007; Buia et al., 2007; Mangialajo et al., 2007; Wells et al., 2007; Guinda et al., 2008, 2014a,b; Juanes et al., 2008; Orlando-Bonaca et al., 2008; Asnaghi et al., 2009; Azzopardi and Schembri, 2009; Iveša et al., 2009; Sfriso et al., 2009; Sfriso and Facca, 2011; Bermejo et al., 2012, 2013a,b; Díez et al., 2012; Neto et al., 2012; Nikolić et al., 2013; Ar Gall and Le Duff, 2014; Ferrigno et al., 2014; Ar Gall et al., 2016; Blanfuné et al., 2016). Most of them are based on sampling along transects or at a few stations along the coast (Mangialajo et al., 2007; Juanes et al., 2008; Asnaghi et al., 2009; Iveša et al., 2009; Bermejo et al., 2012; Neto et al., 2012; Nikolić et al., 2013; Guinda et al., 2014a,b). The CARLIT index (Ballesteros et al., 2007) is the only one to take into account the entire rocky coastline of a coastal WB. In addition, this index is the most widely used in the EU Mediterranean countries (Spain, France, Italy, Malta and Croatia) and in one non-EU country (Albania) (Ballesteros et al., 2007; Buia et al., 2007; Mangialajo et al., 2007; Omrane et al., 2010; Blanfuné et al., 2011; Sfriso and Facca, 2011; Bermejo et al., 2012, 2013a; Nikolić et al., 2013; Ferrigno et al., 2014; Blanfuné et al., 2016).

The CARLIT method is based upon the mapping of mid-littoral and upper infralittoral species and communities of rocky shores that are considered as good descriptors of the environmental water quality. Evidence on the effects of industrial and wastewater discharges have been widely reported for shallow species, highlighting different sensitivity levels for different coastal assemblages (e.g. Bellan-Santini, 1968; Arnoux and Bellan-Santini, 1972; Bellan and Bellan-Santini, 1972; Belsher and Boudouresque, 1976; Belsher, 1977; Chryssovergis and Panayotidis, 1995; Soltan et al., 2001; Terlizzi et al., 2002). Long-lived macrophytes such as *Cystoseira* spp. (Fucales, Phaeophyceae) are evidence of long, relatively disturbance-free periods and good water quality, in contrast to some ephemeral or opportunistic species that respond quickly to any environmental disturbances, such as the articulated red algae of the genera *Corallina* Linnaeus and *Ellisolandia* K.R.Hind & G.W.Saunders (Corallinales, Rhodophyta) and the mussel *Mytilus galloprovincialis* Lamarck, 1819 (Mytiloida, Mollusca), that are indicative of medium water quality, and some species of green algae such as *Ulva* spp., *Cladophora* spp. that usually characterize waters of poor quality (e.g. Fernandez and Niell, 1982; Thomas, 1983; Janssens et al., 1993; Orfanidis et al., 2001; Panayotidis et al., 2004; Arévalo et al., 2007; Ballesteros et al., 2007; Mangialajo et al., 2007; Cecchi et al., 2009; Maggi et al., 2009; Falace et al., 2010; Sfriso and Facca, 2011; Nikolić et al., 2013).

The relevance of biological indices has to be validated by putting them in correlation with the anthropogenic pressures acting in the study area, in order to establish the link between the ecological status of the coastal WB and the biological quality elements (BQE) used. All existing indices have been more or less correlated with pressure indices such as the LUSI Index (Land Use Sustainability Index), but the link has been assessed empirically and not clearly established, or not dealt with at all (Orfanidis et al., 2001, 2003, 2011; Mangialajo et al., 2003, 2007; Panayotidis et al., 2004; Simboura et al., 2005; Ballesteros et al., 2007; Buia et al., 2007; Juanes et al., 2008; Orlando-Bonaca et al., 2008; Azzopardi and Schembri, 2009; Iveša et al., 2009; Omrane et al., 2010; Bermejo et al., 2012, 2013a,b; Díez et al., 2012; Neto et al., 2012; Nikolić et al., 2013; Ferrigno et al., 2014; Guinda et al., 2014a; Ar Gall et al., 2016). Moreover, parameters used to determine the correlation with biological indices were often not relevant pressures for the species and communities considered. A relevant link requires that the considered pressures would have an actual impact on species or communities of interest, and would be quantifiable at the scale of a WB and for all the water bodies considered.

The aims of this study are i) to assess the ecological status of the water bodies of the French Mediterranean coasts by means of the CARLIT method, the first assessment undertaken over such an extensive shoreline (~2 970 kilometres), ii) to calculate the relationship between the CARLIT index and different, already-existing anthropogenic pressure indices, iii) to propose and to test a new index of anthropogenic pressures (HAPI), better correlated with the CARLIT index than previous pressure indices, iv) to discuss changes in the CARLIT index scores between two successive surveys (2007–2010 vs 2012–2015), and v) to discuss possible improvements to the CARLIT index, requiring less expert judgement and making it easier to implement by local authorities.

2. Material and methods

2.1. Study area and coastal water bodies

The CARLIT method only applies to coastal water bodies dominated by rocky shores where macrophytes can be used as BQE.